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The FRONTIERS plan: a strategy for using radar and satellite imagery for very-short-range precipitation forecasting*

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Summary

The FRONTIERS program described in this article addresses the problem of analysing and forecasting the detailed pattern of precipitation over the period 0–6 hours ahead. The acronym FRONTIERS embodies the following key elements: Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite. In this program we adopt a whole-system design approach, with digital data handling all the way from the observational input to the disseminated forecast product. We also emphasize the crucial role of human judgement which is required to make up for the limitations of the observational data and the incompleteness of our understanding on the mesoscale. In the plan discussed here the data from a network of radars and a geostationary satellite are composited on an interactive video display and the forecaster does his analysis and forecasting by modifying what is on the television screen whilst preserving the basic data in store. The resulting screenful of digital information can then be tailored and disseminated promptly to users without further manual effort. Although the emphasis in this paper is on the accurate analysis of current weather and extrapolation of current trends, these methods must be considered in the context of an eventual forecast system incorporating a mesoscale numerical model.

Introduction

The progress in synoptic-scale weather forecasting brought about during the past two decades by developments in numerical–dynamical methods has not been matched by progress in forecasting for the period from 0 to 6 hours ahead. Nowhere has this lack of improvement been more evident than in the case of precipitation. One of the main difficulties has been the lack of suitable observational data on the mesoscale. However, many meteorologists have for a long time had a vision of radar and satellite data doing for very-short-range forecasts what radiosonde data have enabled numerical–dynamical models to achieve on the larger scales. The time is now ripe for this dream to be turned into a reality, and in this paper we describe a specific strategy for generating very-short-range forecasts of precipitation in the United Kingdom. The strategy will be implemented as part of the Short Period Weather Forecasting Pilot Project which began in 1978 (Browning 1977). The aims of this project are to lay the foundations for improved very-short-range forecasts by setting up new observing and data-handling facilities, developing analysis and forecasting techniques and increasing our fundamental understanding of mesoscale weather systems.

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* This article is part of a longer report, *Meteorological Office Radar Research Laboratory Research Report*, No. 11, January 1979, by K. A. Browning, C. G. Collier and P. Menmuir, a copy of which is held in the National Meteorological Library, Bracknell.

Radar and satellite data have already been used semi-operationally for subjective forecasting (nowcasting) 0 to 6 h ahead (e.g. Scofield and Weiss 1977). Objective extrapolation of radar data has been employed semi-operationally by Bellon and Austin (1978). Our plan calls for the use of radar and satellite information as a merged whole, with all-digital data handling from data input through to final dissemination of the forecast product; the plan also calls for the use of objective extrapolation procedures. However, a further crucial ingredient is a large degree of man–computer interaction in both analysis and forecasting, exploiting the video display techniques pioneered by V. Suomi's group at the University of Wisconsin. The name FRONTIERS applied to our plan incorporates the key elements of the program, namely: Forecasting Rain Optimized using New Techniques of Interactively Enhanced Radar and Satellite.

Although the emphasis in the FRONTIERS program is on the accurate analysis of current weather and the extrapolation of current trends as identified by radar and satellite, these methods must be considered as part of a total system such as that depicted in Figure 1 (Kreitzberg 1976). The part of the system dealt with in this paper (see the dashed rectangle in Figure 1) will eventually be linked to a new generation of mesoscale numerical weather prediction models (Carpenter *et al.* 1978). This linkage will need to be a two-way process, with simple very-short-range forecasts generated by extrapolating the radar-cum-satellite data being modified in the light of output from a mesoscale numerical weather prediction (NWP) model, and the model itself using inputs from the radar and satellite (and other) sources. The patterns of precipitation derived in the manner discussed in this paper may not be useful in their own right for initializing the numerical model, but the implied fields of humidity, vertical velocity and latent heat release probably will be (Kreitzberg and Rasmussen 1977).

This paper presents the guiding principles of a plan which will take several years to implement. Almost certainly, the details of the plan will change as it is implemented. However, the underlying strategy is expected to endure and, since it could have a substantial impact on local forecasting practice, the author believes that it is important to expose the strategy to critical discussion by the research and forecasting community while the program is still in its infancy.

The elements of a system for deriving very-short-range forecasts of precipitation in the United Kingdom

In this section we present a check-list of the important elements that constitute the proposed radar-cum-satellite system, but first we stress the need to view the scheme as a *whole system*. There would be little sense, for example, in having an observational capability without adequate means of assimilating and interpreting the data, or in having the means of generating detailed very-short-range forecasts without the capability of disseminating so perishable a product in a speedy fashion to the eventual users.

The elements of the forecasting system are as follows:

(i) *The radars*

Experiments such as the Dee Weather Radar Project (Central Water Planning Unit 1977) have demonstrated that a high degree of quantitativeness can be achieved in the radar measurement of surface precipitation intensity, even in difficult hilly areas, provided that the radars are calibrated using telemetered rain-gauge data. Moreover, modern radars, with the benefit of solid-state technology, are capable of stable and reliable operation for long periods and so they can be operated unattended (Try 1972, Aldcroft 1976). This enables them to be sited optimally and to be run with low labour costs. By using a mini-computer at each radar site preprocessed* rainfall data can be sent in

* Throughout this paper 'preprocessed' is used in the sense 'having been subjected to preliminary processing' rather than 'having been processed in advance'.

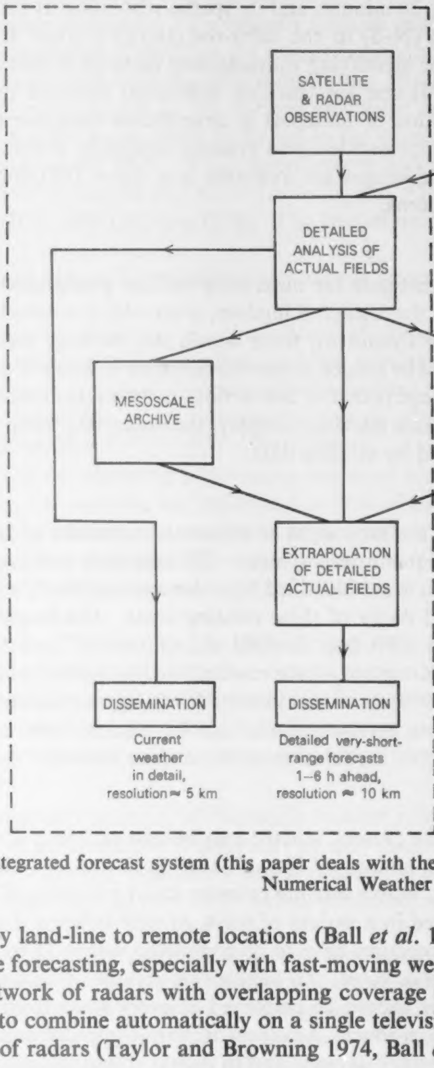

Figure 1. Integrated forecast system (this paper deals with the part enclosed within the dashed rectangle). NWP = Numerical Weather Prediction.

real time by land-line to remote locations (Ball *et al.* 1976, Saffle 1976). One of the requirements for short-range forecasting, especially with fast-moving weather systems, is to have large-area surveillance using a network of radars with overlapping coverage (Hill *et al.* 1977). Thus techniques have been developed to combine automatically on a single television display the digital data being received from a network of radars (Taylor and Browning 1974, Ball *et al.* 1979b).

(ii) *Geostationary satellite imagery*

Satellite-borne microwave techniques are capable of measuring precipitation directly over the oceans (Wilheit *et al.* 1977) but their spatial resolution is poor. Moreover these techniques have as yet been used only on polar-orbiting satellites and these cross any given area too infrequently to be of great value for very-short-range forecasting. The European geostationary satellite Meteosat, on the other hand, although not instrumented to observe precipitation directly, is capable of providing *cloud* imagery with a resolution in time and space which does satisfy the basic needs of very-short-range

forecasting. The time resolution of Meteosat is 30 minutes and its spatial resolution at the latitude of England and Wales is 6 km (E–W) and 12 km (N–S) in the infra-red (IR) (3×6 km in the visible (VIS)). Although better resolution is needed for identifying characteristic patterns of cumulus heralding outbreaks of thunderstorms (Purdom 1976) and for tracking individual cumulus to determine low-level winds (Fujita *et al.* 1975), the resolution of Meteosat is nevertheless adequate for keeping track of the important precipitation-producing mesoscale cloud systems, especially if occasional (say, 6-hourly) high-resolution polar-orbiting satellite images are available (e.g. from TIROS-N) to assist in the interpretation of the Meteosat cloud patterns.

(iii) *The marriage of radar and satellite data*

Ground-based radar is superior to satellite methods for measuring surface precipitation intensity, but the coverage of radar is rather limited. In the United Kingdom, even with a network of radars, perhaps linked eventually to a network on the Continent, there would still be large areas over the surrounding sea for which the satellite data would be needed to provide advance warning of approaching precipitation systems. Thus the principle we adopt is that of converting the two sets of data to a common format so that they can be merged on the same television display, the radar data being used where possible and the overall coverage being extended by satellite data.

(iv) *The emphasis on advection*

The role of radar and satellite is to watch for the early signs of mesoscale outbreaks of precipitation and to keep track of their movement and subsequent development. The emphasis in this paper is on forecasting by advection of existing precipitation areas identified by radar and satellite*, together with some assessment of the likely development and decay of these existing areas. The emphasis on advection—which differs from that adopted in the USA (e.g. Scofield and Oliver 1977)—is appropriate for much of the time in places like the United Kingdom where most of the precipitation is associated with frontal disturbances. Hill and Browning (1979) show that in these frontal systems some convective mesoscale precipitation areas show considerable persistence and can be tracked over hundreds of kilometres as resolvable entities despite orographic modulation of the surface rainfall.

(v) *Digital data handling*

A single satellite IR image as considered in the present scheme may consist of 256×256 cells each with up to 256 radiance levels assigned to it, i.e. almost 10^6 bits of data. Such images will need to be compared and combined with other images (e.g. visible satellite or radar data) and parts of the images will need to be rapidly accessed and manipulated in a variety of ways, as well as being displayed and disseminated in different formats. All these procedures have to be completed within 15 to 30 minutes if the forecast is to be issued soon enough to be of value. To handle this volume of data flexibly and rapidly, without degrading it, digital techniques should be employed at every stage from the observational input to the final dissemination of the product. Advances in mini-computer and microprocessor technology, in solid-state fast-refresh memory devices, and in digital communications systems, now make it possible to achieve this at reasonable cost.

* In order to address the problem of forecasting the initial outbreak of deep convection it will of course be especially important to supplement the satellite imagery with mesoscale surface observations (e.g. from automatic weather stations). Moreover, it is to be hoped that later versions of Meteosat will provide higher-resolution cloud imagery for use in thunderstorm situations and will also be capable of providing profiles of temperature, humidity and wind in the manner discussed by Smith *et al.* (1978). Although not addressed in this paper, these other techniques are receiving a lot of attention in the USA where the sudden outbreak of severe tornadic storms is a matter of great concern.

(vi) *Interactive computer-driven video displays*

Video display techniques have recently become available which, when linked to a small computer, provide the capability of recalling the required image almost instantly and of permitting a large amount of human interaction with the television display (Hilyard 1977). These techniques provide the key to the rapid performance of the various analytical and forecasting steps described later. Work on interactive displays in the early 1970s led to the development of a display system known as McIDAS (Chatters and Suomi 1975). Other more recent systems in the USA include AOIPS (Bracken *et al.* 1977), ADVISAR (Smith and Reynolds 1978) and NEDS (Thormeyer 1978). In the United Kingdom there is the IDP-3000 (Balston 1978). The kind of activities that can be carried out using such systems are:

- *Rapid data access*, i.e. almost instantaneous selection of any required image from a set of stored images.
- *Precision navigation*, i.e. x–y translation of the image to remove residual registration errors by reference to electronically generated coastline overlays.
- *Enhancement (contrast-stretching and level-slicing)*, i.e. adjusting grey shades or assigning colours at variable thresholds, either to make features of interest stand out or for the purpose of calibrating the intensity levels.
- *Animation*, i.e. replaying a time-lapse sequence of images.
- *Zooming*, i.e. selecting and enlarging an area of interest.
- *Image combination*, i.e. combining or comparing with great precision the images from different sources, e.g. radar and satellite, or satellite IR and VIS.
- *Superposition of graphics*, i.e. capability of superimposing geographical features, labels, numerical data, and line charts.
- *Intervention*, i.e. modification of the image data within areas delineated by means of a movable cursor whilst preserving the original data in store.

These activities can be carried out rapidly by means of simple analogue controls (e.g. a joystick) plus keyed-in instructions. Later on we shall discuss a specific sequence of steps whereby it is planned to generate detailed analyses and very-short-range forecasts of precipitation entirely on the television screen itself.

(vii) *Improved understanding of mesoscale weather systems*

The use of an interactive display can be only as good as the state of meteorological understanding will permit. Thus, for example, a major problem is to convert the radar and satellite data into fields which represent the true pattern of surface precipitation intensity as faithfully as possible. The transfer function is reasonably well established for the radar and much of the analysis of the radar data has to do with improving accuracy and removing unwanted echoes; however, the transfer function for converting satellite cloud data into surface precipitation intensity is not well established, especially in mid-latitudes where much of the precipitation is non-convective and there is abundant cirrus in regions far removed from areas of surface precipitation (Barrett 1973). In this case we need to use a combination of approaches:

- Empirical adjustment of satellite data to correspond to precipitation intensities given by *ground truth* or by *nearby radar data.*
- Exploitation of the *different spectral response* in different satellite channels. For example, Reynolds *et al.* (1978) and Lovejoy and Austin (1979) exploit the fact that whereas the IR radiance is a measure of cloud height, the visible brightness tends to be more a measure of cloud thickness. Consequently low (cold) radiance values together with high brightness is indicative of precipitating cloud while low radiance coupled with low brightness is indicative of cirrus alone.

- Exploitation of the *texture* of high-resolution visible data from occasional passes of a polar-orbiting satellite to reveal the presence of characteristically fibrous cirrus which otherwise might be interpreted as being deep rain-bearing cloud.
- The use of *conceptual models* relating cloud patterns to surface precipitation in different synoptic situations (Kreitzberg 1969). A simple example is the fact that the leading parts of baroclinic disturbances have considerable upper cloud unrelated to surface precipitation, whereas the trailing parts of such disturbances are more convective and the high cloud tops tend to be better related to the occurrence of precipitation. At present most of the conceptual models are biased toward the synoptic scale, the few mesoscale models (Browning 1974, Houze *et al.* 1976) being derived from a limited number of detailed case studies. However, when the kind of analysis described in this paper is carried out on a more regular basis, we shall begin to accumulate the raw material for the derivation of a more systematic classification of mesoscale cloud and precipitation patterns.

Much fundamental research remains to be done to improve all aspects of the analysis of satellite data. More research is also needed to enable us to derive forecasts from the analysed precipitation fields. It is sometimes possible for useful forecasts for a few hours ahead to be obtained simply by linear extrapolation. However, it will be important to develop methods to predict the development or decay of existing precipitation patterns that results from both internal dynamical factors and from external topographical forcing. Approaches to be used will include:

- Incorporation of large-scale trends predicted by synoptic-scale or mesoscale numerical–dynamical models.
- Incorporation of topographical enhancement factors derived from mesoscale climatological statistics and from simple diagnostic models.

It will be possible to implement these approaches in a fully satisfactory way only when a substantial body of experience has been amassed concerning the way in which mesoscale precipitation patterns evolve. In particular, a precipitation archive* needs to be established on the basis of detailed radar and satellite data which have been carefully combined and quality-controlled to remove obvious errors and unwanted echoes.

(viii) *Optimizing the man–machine mix*

Many of the steps in the analysis and forecasting procedure (described later in this paper) can easily be automated and, in time, more of the steps will become amenable to automation; however, it is difficult to foresee a time when the observational data on the mesoscale will be good enough to eliminate the need for considerable human judgement. The use of an interactive video display will permit the man–machine mix to be optimized by automating the repetitive tasks whilst enabling the forecaster to retain and indeed expedite the use of his judgement. As discussed by Woodroffe (1976), use is already made of a visual display unit interactively connected to a computer for the purpose of manually intervening in the objectively analysed fields used as input to the Meteorological Office 10-level model. The approach advocated in this paper involves a considerable extension in the degree of interaction. Instead of using satellite and other information to adjust values at a limited number of widely spaced grid points, the approach here is to use the detailed radar-cum-satellite information

* In addition to the importance of a mesoscale precipitation archive for forecasting, such an archive would also be valuable for off-line hydrometeorological applications. According to Bussell *et al.* (1978), considerable savings could be made by reducing the UK network of rain-gauges if a reliable radar-rainfall archive could be maintained. However, to achieve the accuracy required for many hydrometeorological applications, data from a radar-rainfall archive (consisting of data analysed as described later in this paper) would need to be combined off-line with data from a rationalized network of autographic gauges so as to generate what Harrold *et al.* (1974) refer to as an 'optimum rainfall field'.

itself as the primary material and to adjust it to bring it into conformity with other constraints so as to achieve the best possible representation of the mesoscale field of precipitation. This requires repeated modification of a dense matrix of data points and implies a far larger amount of interaction than is currently regarded as normal.

(ix) *Dissemination of the forecast product*

Existing methods of disseminating forecasts are inadequate to do justice to the wealth of perishable information likely to be contained in the forecasts generated using radar and satellite data. One approach in the future will be to transmit automatically a limited amount of digital data precisely tailored to individual users' needs. As Carpenter *et al.* (1978) point out, the increasing use of on-site microprocessor control systems and of dial-up computer access will make automatic response to such forecast information more feasible. It will also be necessary to make more use of local radio, especially techniques for providing flash messages to travellers (e.g. 'Carfax'). Another approach will be to send out picture information from which the user can select for himself the information which interests him. The information should be frequently updated, the most recent data being accessible continuously on demand rather than intermittently at scheduled times. A number of options exist for this approach; they include:

- *Special-purpose equipment* capable of receiving and storing digital data transmitted by standard lines and of replaying one picture or a sequence of pictures on a television set. Simple devices of this kind are commercially available and are coming into use in the Meteorological Office and in some Water Authority offices (Taylor 1975, Ball *et al.* 1979a).
- *Teletext ('Ceefax' and 'Oracle')*. In this scheme the data would be sent in a spatially degraded format to a television broadcast company via a computer-to-computer link and could be displayed on demand on domestic television sets equipped to receive teletext.
- *Viewdata (e.g. the 'Prestel' system described by Parker 1978)*. This is similar to teletext except that the data would be sent to regional computers operated by the telephone company and would then be called up on a domestic television set by telephoning the computer data bank. In addition to providing a larger bank of data specially tailored to the needs of the area served by the regional data bank, the viewdata system has the advantage over teletext that it could generate revenue for the data provider in direct proportion to the demand for the product (Meteorological Office 1978). The viewdata system could also permit the monitoring of the demand for individual forecast products, which is an important requirement for the development of a sound marketing plan.

A specific scheme for deriving very-short-range forecasts of precipitation in the United Kingdom

(a) *General survey of the scheme*

The FRONTIERS system concept outlined above is being implemented within the Short Period Forecasting Pilot Project at the Meteorological Office Radar Research Laboratory. As part of this program a pilot network of, initially, four radars* is being established in England and we shall be combining the data from these radars with Meteosat data reduced to a radar-compatible format. We are proceeding on the assumption that there will be a continuing service of geostationary imaging for north-west Europe. In this section we shall be describing a sequence of steps forming a systematic work flow pattern for the derivation of current weather and forecast products from the radar and

* The radars are a mixture of C- and S-band sets with 1- and 2-degree beams, respectively. One of the radars is new; the other three radars in this interim network are not so up to date. The new radar is being funded by a consortium of government agencies as part of the North West Radar Project.

satellite data. Some of the steps are straightforward and have already been implemented. Others are more complex and will require several years of experience or the accumulation of an archive of data before they can be implemented satisfactorily. Yet others may turn out to be too time-consuming or costly in relation to their effectiveness to justify inclusion in the final scheme. Only practical experience will indicate what operational compromises will be required. Clearly the system must be designed with a view to evolutionary robustness. Although it will be several years before the precise form of the forecasting procedures will emerge, we consider it worth while at this stage to describe our present plans in some detail as a means of clarifying the problems that have to be addressed.

The principal stages in the proposed forecasting scheme are shown in Figure 2. The four main stages—preprocessing, meteorological analysis (including quality control), forecasting, and dissemination—will be elaborated upon in Figures 3 to 6. The two other areas of activity shown in Figure 2—archiving and forecast validation—will be automated and carried out in parallel with the Stage 2 and Stage 3 activities. Although the hardware facilities will be the subject of a later paper, it is appropriate to mention here that a mini-computer is required at each of the radar sites to perform the Stage 1 preprocessing (we are using the PDP–11 series of computers). Similar computers are needed to process the satellite data and to receive and combine the data from the network of radars. A further mini-computer is required to drive an interactive video display system. The radar data available at the network centre are in 8-bit format. At the moment we are making the best possible use of redigitized analogue data from Meteosat together with a very simple interactive display, but the scheme outlined here is based on the use of 8-bit digital data from both satellite and radar together with a versatile interactive video display.

(b) *Preprocessing of the satellite and radar data*

A breakdown of the activities involved in the preprocessing stage is shown in Figure 3. The on-site radar data processing is essentially as described by Taylor and Browning (1974). Two categories of data are available at the network centre. One category—areal integrations—is for hydrological use and is not used subsequently for meteorological forecasting. The other, meteorologically important, category of data is a radar composite map available every 15 minutes on a 256×256 grid with 5 km* resolution. This map is displayed on a television screen (and is also available as hard copy). The radar rainfall patterns are stored and can be manipulated in 8-bit form, i.e. 256 levels of intensity, although for ease of interpretation only eight levels are likely to be displayed at any one time. The standard display system, for example, has a different colour for each of the following precipitation categories: L, 1, 4, 8, 16, T, H, where L = light rain, T = probable thunder shower, H = probable hailstorm, and the numbers refer to rainfall intensity thresholds in millimetres per hour averaged over each 5 km square. The reason for storing the data as 256 levels is to reduce quantizing errors during the subsequent Stage 2 and 3 processing when a whole series of correction factors has to be applied.

As far as the satellite data are concerned, Figure 3 shows that we intend to concentrate on the use of the frequent imagery available from Meteosat. There are three channels of interest: infra-red (IR), visible, and perhaps water vapour. These data are available at 30-min intervals for the IR, and also for the visible during daylight hours, but less frequently for the water vapour channel. The IR channel, representing approximately the temperature of the cloud top, is available around the clock and so is treated as the primary satellite data for precipitation forecasting; however, the facility will be provided for automatically combining the IR data with the other channels, at times when they are available, according to empirical rules developed by off-line research, in order to improve the delineation of the probable extent of surface precipitation.

* Data over limited areas with a resolution of 2 km and 5 min are also available for off-line research.

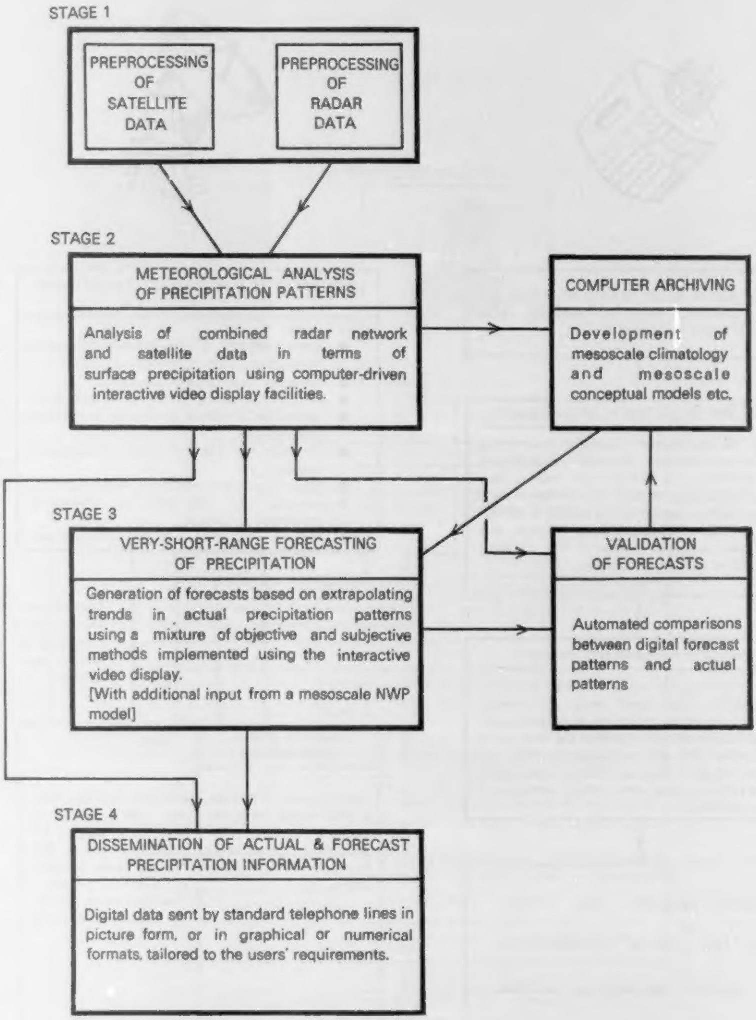

Figure 2. Outline of scheme for very-short-range precipitation forecasting (showing major stages only).

One of the first tasks with the satellite imagery is to convert it automatically to the same projection as the radar data. The next step is to use the coastlines to locate the images with the high degree of precision required for local forecasting purposes. This is the registration or so-called navigation procedure. The 256 radiance levels available from Meteosat give ample scope for colour enhancement to make the coastlines stand out clearly. The interactive display is used to position the image on a

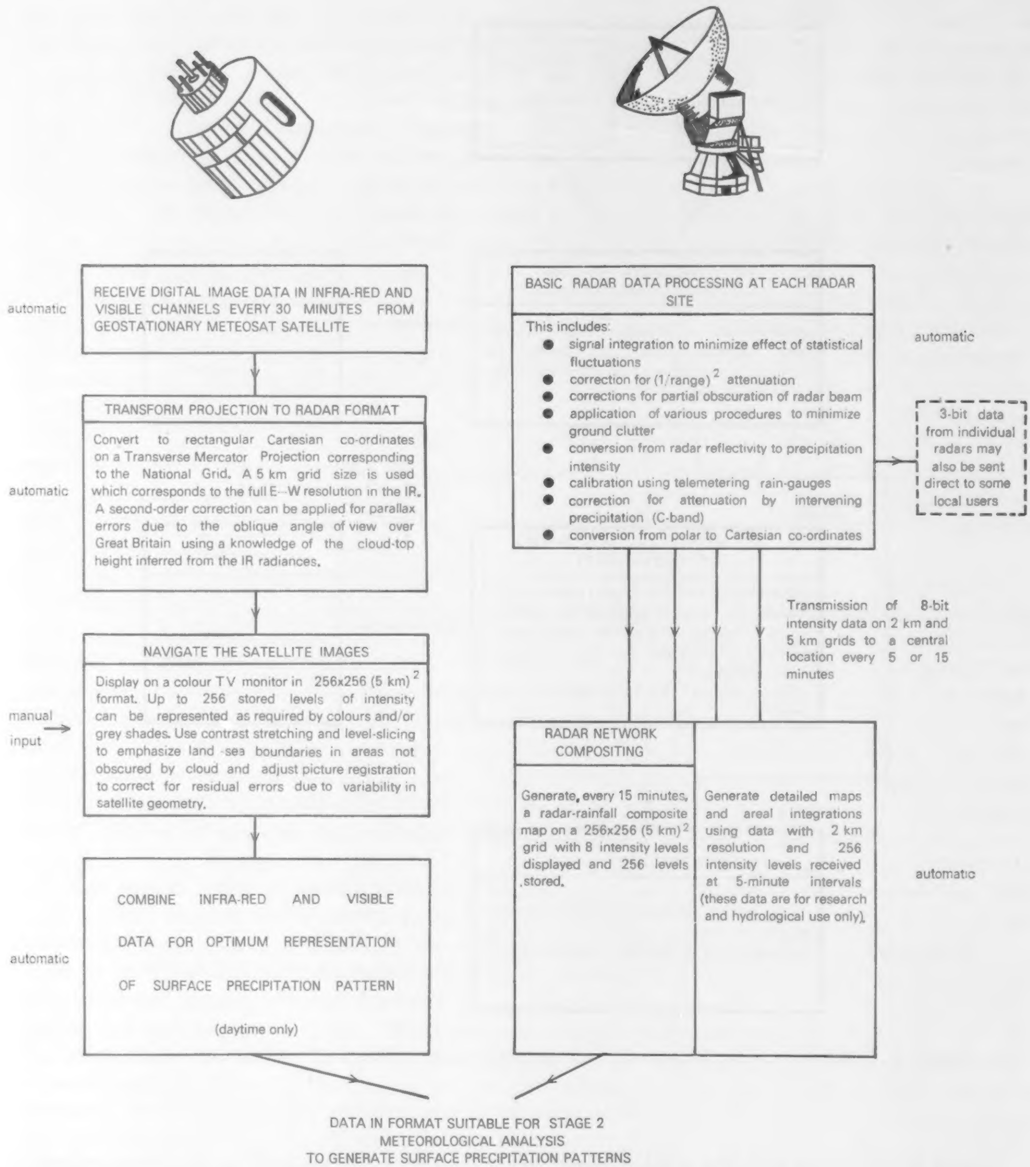

Figure 3. Stage 1: Preprocessing of satellite and radar data.

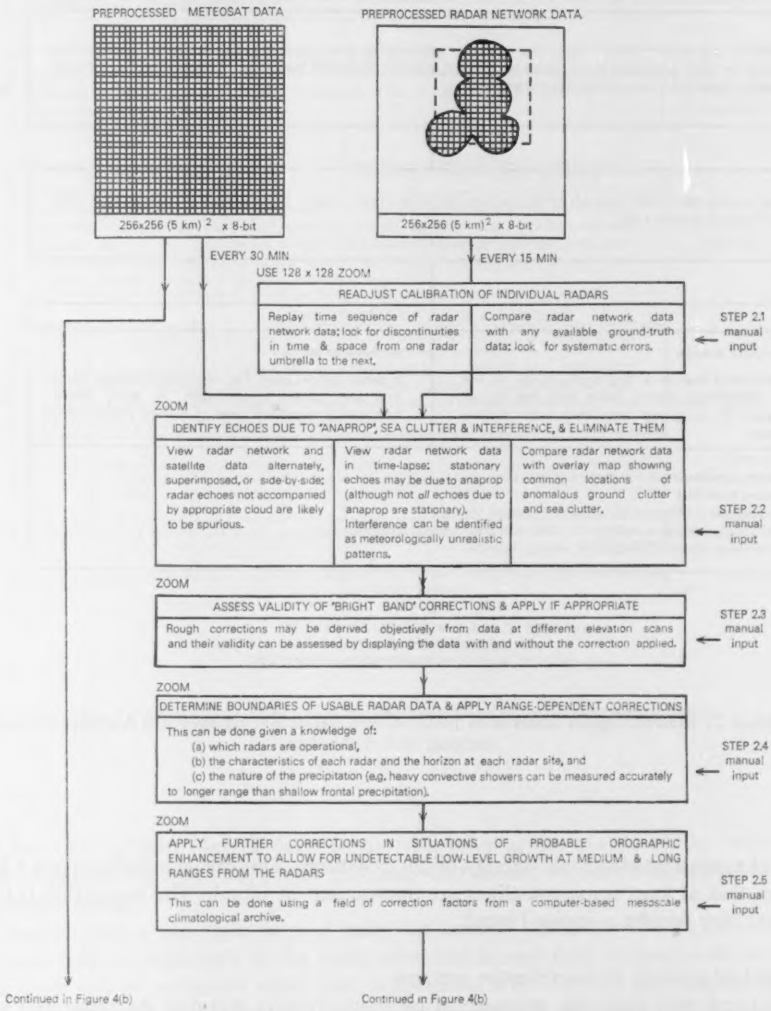

Figure 4(a). Stage 2: Meteorological analysis of precipitation patterns (a) Corrections to the radar network data.

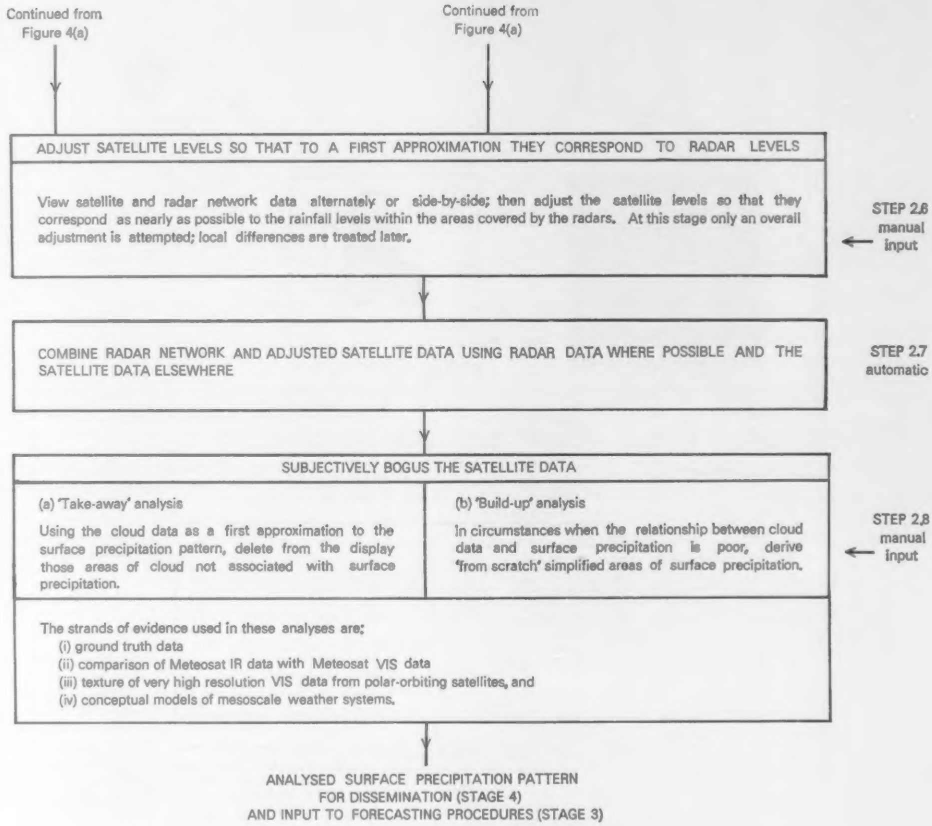

Figure 4(b). Stage 2: Meteorological analysis of precipitation patterns (*continued*) (b) Analysis of satellite data and merging with radar data.

256×256 grid against an electronic overlay of the coastline. This image usually covers a large enough area to ensure that at least some coastlines are unobscured by cloud. The navigation is the only task in Stage 1 that may require a manual input.

(c) *Meteorological analysis of precipitation patterns*

Figures 4(a) and 4(b) show the sequence of tasks involved in merging the radar and satellite data sets and in analysing them in terms of surface precipitation intensity. The input data sets at the top of Figure 4(a) are preprocessed data in common formats, with the entire 256×256 $(5\ \text{km})^2$ array filled with Meteosat data but only a part of the array filled with data from the limited-area UK radar network.

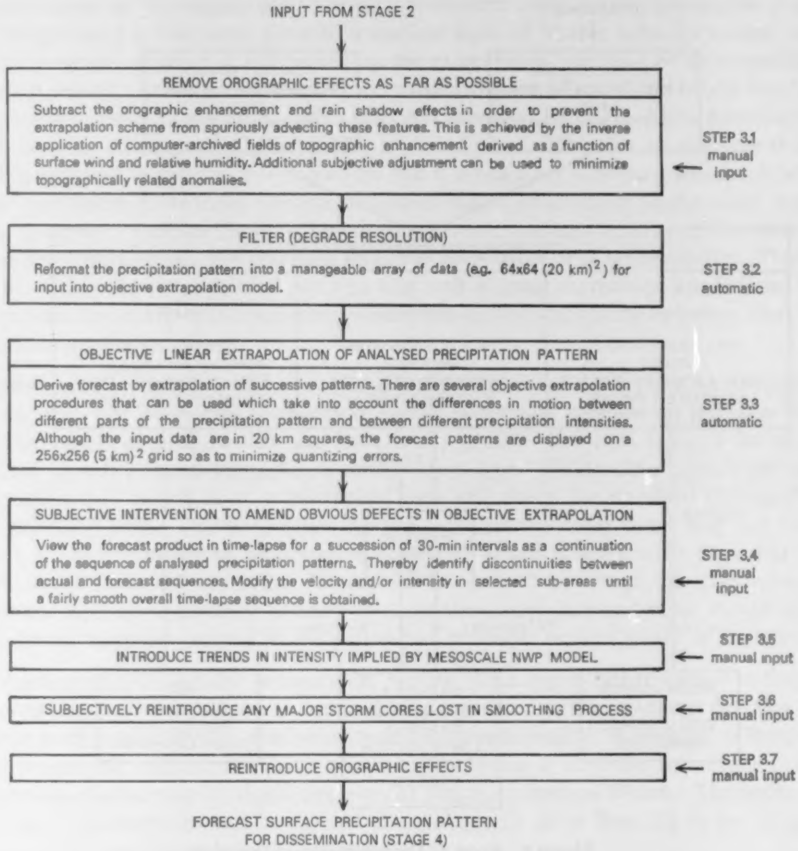

Figure 5. Stage 3: Very-short-range forecasting of precipitation patterns.

The first five tasks (Figure (4a)) all have to do with refining the quality of the radar rainfall data on the basis of manual inputs to cope with problems that cannot be fully dealt with objectively in the radar-site preprocessing:

Step 2.1: Readjustment of the calibration of individual radars. Although it is planned that individual radars will normally be calibrated at the radar sites and in real time by means of telemetered rain-gauge data, there will be occasions when such calibrations will either be unavailable (e.g. because of lack of rain over the calibration gauges) or unreliable (e.g. because of contamination of the radar beam by the strong echo from melting snow at the range of the calibration gauges). Any overall radar calibration errors arising from such effects can be identified in one of the ways indicated in Figure 4(a) and then appropriate adjustments can be made using the interactive display facilities.

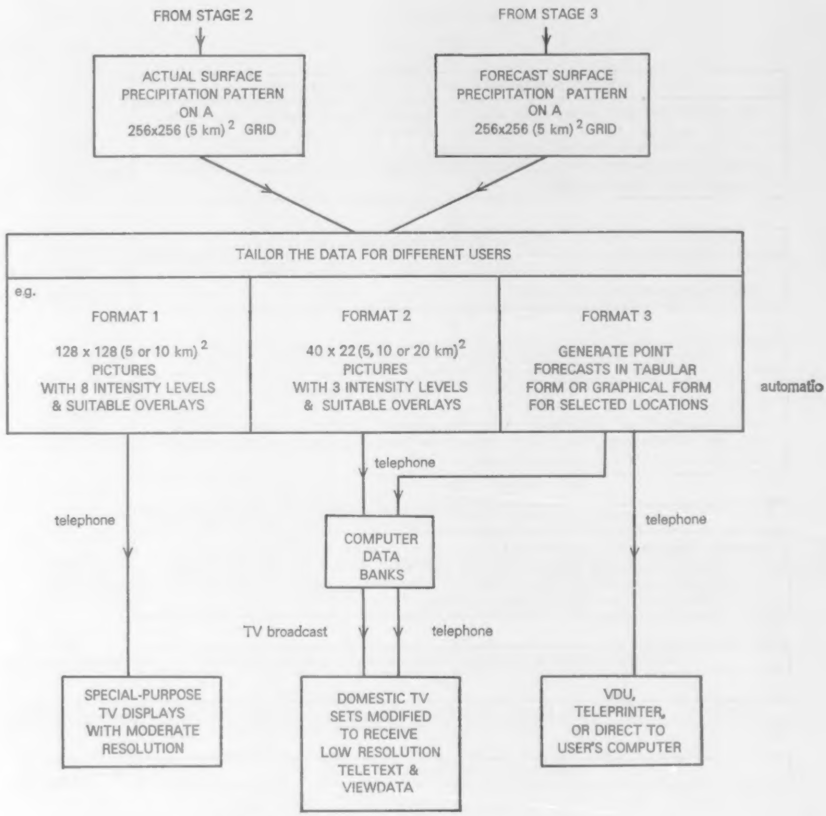

Figure 6. Stage 4: Dissemination to the users.

Step 2.2: Identification and eradication of spurious echoes due to anomalous propagation, sea clutter and radar interference. Techniques have been developed which make use of the fluctuating characteristics of the radar signal to enable precipitation targets to be distinguished from ground echoes, including those associated with anomalous propagation (Johnson *et al.* 1975). These techniques have yet to be implemented operationally and, if they do not provide a complete solution, the additional procedures shown in Figure 4(a) can be applied subjectively to reject any remaining echoes of this kind. Before applying any correction the analyst should of course ascertain whether the atmospheric conditions are conducive to the production of anomalous propagation. Sea clutter probably cannot be distinguished from precipitation on the basis of its fluctuation characteristics and its presence will have to be inferred from the expected sea state or, in ideal circumstances, from the absence of satellite-observed cloud in the area. Radar interference can generally be recognized by its characteristic configuration, e.g. radial spokes and spirals. Once identified, these unwanted echoes can be removed from the video display by means of manual inputs.

Step 2.3: Assessment of the validity of bright-band corrections and their implementation if appropriate. The radar bright band is the name given to a shallow layer of intense echo associated with melting snow which, at ranges where it is intersected by the radar beam, can lead to an overestimate in the precipitation intensity. An objective method for minimizing the effect of the bright band using data from radar scans at different elevation angles has been proposed by Harrold and Kitchingman (1975). Subsequent tests by Clarke and Collier (1977) have indicated difficulties in applying it in practice. More work is required to develop this procedure and it is not clear at present whether it will be better to apply the correction at the radar sites for individual radars or centrally on the radar composite. In either case, however, there are likely to be occasions when, perhaps because of the inhomogeneous character of the precipitation, the resulting objective corrections will be unreliable. Thus there will be a need to display the radar rainfall patterns with and without corrections applied and to use subjective judgement to exploit man's superior pattern recognition capability to assess what corrections if any should be applied.

Step 2.4: Determination of the boundaries of usable radar data and the application of range-dependent correction factors. The horizontal boundary of usable radar data depends on the radar horizon and on the vertical extent of precipitation and its intensity profile. For each radar, a set of boundaries can be defined for a few broad categories of precipitation type. Within these boundaries at the longer ranges correction factors will need to be applied over and above the standard $(1/\text{range})^2$ correction applied at the radar sites. This is to allow for the fact that the radar beam may not be filled with precipitation or may be sampling precipitation echo aloft which is less intense than that close to the ground. Fields of statistical correction factors can be derived by comparing daily-integrated radar rainfall patterns with corresponding patterns of daily rain-gauge data and these should be computer-archived in broad categories related to the nature and probable vertical extent of the precipitation.

Step 2.5: Application of orographic enhancement factors. This step is rather similar to Step 2.4 except that the corrections will be confined to exposed hilly areas and will be a strong function of the conditions at low levels, especially the wind velocity and relative humidity. According to Browning (1979), substantial orographic enhancement can occur in the lowest 1 or 2 km in certain circumstances, and the correction factor may be significant even at ranges as close as 50 km. The correction factors due to low-level enhancement can be derived climatologically as in Step 2.4 or by using diagnostic fine-scale numerical models such as that of Bell (1978).

Step 2.6: Adjustment of the satellite levels so that to a first approximation they correspond to radar levels. Having bogused the radar network data in Steps 2.1 to 2.5, the next step is to compare the satellite IR data (or some automatically derived combination of IR and VIS data) with the by-now optimized radar data and to adjust the satellite level-slicing scheme for the display as a whole to correspond as nearly as possible to the rainfall levels used in the radar scheme (Figure 4(b)).

Then, as Step 2.7, the radar and adjusted satellite data are composited on the same display using the radar data where available and filling in the gaps with the satellite data.

Step 2.8: Subjective bogusing of the satellite data. We then come to one of the most challenging tasks, namely modifying the parts of the display that are based upon the satellite data* in order to remove

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* Step 2.8 is described assuming that the satellite data are based upon IR information only, as for example during the night. The combined use of IR and VIS data, as described by Lovejoy and Austin (1979), may by itself provide a fairly good indication of the extent of precipitation. Even then, however, an abbreviated application of Step 2.8 should significantly improve the analysis.

areas of high cloud not associated with precipitation and to introduce any areas of precipitation associated with rather shallow cloud. Two approaches can be used depending on how close the correspondence is between the satellite cloud pattern and the precipitation pattern. We shall refer to these as the 'take-away' and 'build-up' methods, respectively. In cases where there appears to be a reasonable overall correspondence between the areas of high cloud and precipitation, the satellite radiance patterns are used as a first approximation to the detailed precipitation pattern outside the areas of radar cover and the main analysis task is to 'take-away' areas of high cloud which are believed not to be associated with surface precipitation. In regions dominated by convection it is relatively easy to relate high cloud-tops to precipitation cores but in areas of extensive high layer cloud (e.g. at warm fronts) it may not be obvious where the precipitation areas at the surface begin and end. Deciding what cloud to take away then requires the skilful weighing of diverse strands of evidence such as may be gleaned from surface observations, and the texture of the visible cloud observed by polar-orbiting satellites. These pieces of evidence must be reconciled by the human analyst with his knowledge of conceptual models of precipitation systems.

The other method of analysis, referred to as the 'build-up' method, is applied when the overall correspondence between cloud radiance and surface precipitation is so poor that it is necessary in effect to 'wipe the slate clean' outside radar range and to build up the main features of the precipitation pattern from scratch. In this case one would not use the detailed pattern of Meteosat imagery as a direct indication of the detailed pattern of precipitation but, instead, one would recall it on to the screen for use as just one strand along with the other strands of evidence to delineate a rather crude outline of the probable extent of surface precipitation. With this approach the tendency would be to look for characteristic cloud patterns thought to be associated with specific categories of mesoscale organization. A case in point would be the heavy precipitation that often occurs in association with the 3 km tops of convective line-elements at sharp ana-cold fronts (Browning and Harrold 1970, James and Browning 1979). Sometimes, too, it is possible for the human analyst to discern bands of medium-level cloud associated with surface precipitation lying beneath upper cloud bands of different orientation associated with non-precipitating cirrus.

Implementation of the changes to the display called for in Step 2.8 can be achieved using a joystick-controlled movable cursor to define the corners of polygons within which the required modifications can be effected by means of simple keyboard instructions. Different modifications may be required in different geographical sub-areas; in some of these areas 'take-away' analysis may be possible whilst in others the cruder 'build-up' analysis may be needed. Having finished Step 2.8, one has on the screen a fully analysed precipitation pattern on a 256×256 $(5\ \text{km})^2$ grid which is ready for immediate transmission to users interested in current weather or for input to the Stage 3 forecasting procedures. Too much accuracy must not be expected from the analysis in Step 2.8; in some situations one will have done well even if one succeeds in delineating the major areas of rain/no rain. In any case we must remember that the critical land areas will be covered more quantitatively by radar and that the primary role of the satellite is to provide a larger-scale context and some advance warning of approaching areas of precipitation.

(d) *Very-short-range forecasting of precipitation patterns*

The analysis of precipitation patterns in Stage 2 was carried out using 256 levels of intensity in order to retain the contrast enhancement facility for the satellite data and to avoid quantizing errors during the application of successive correction factors to the radar data. Further corrections will need to be applied during the forecast procedure but the level of precision justified at this stage is less; thus the number of intensity levels stored can be reduced.

Figure 5 suggests that the sequence of steps in the forecasting of precipitation patterns should be as follows:

Step 3.1: Removal of orographic effects. The principal step in the forecast procedure is the objective extrapolation of the analysed precipitation pattern (Step 3.3). In order to avoid the mistaken impression that the entire pattern of precipitation is almost stationary, or the possibility of the extrapolation procedure spuriously advecting orographic maxima or rain shadows, it is first necessary to minimize the topographical effects as far as possible. This is achieved by cancelling the enhancement factors applied in Step 2.5, followed by the inverse application of a computer-archived field of topographical radar echo enhancement factors derived climatologically as a function of wind velocity and relative humidity. The objective corrections will be only a first approximation and further subjective tuning may be required to diminish probable topographically related anomalies.

Step 3.2: Filtering of the data. The previous corrections in Step 3.1 do not have to be applied too painstakingly since we may next need to smooth the 256×256 (5 km)^2 array to one of, say, 64×64 (20 km^2)* before applying the objective extrapolation procedure. This smoothing would be done to enable the objective extrapolation to be carried out in a reasonably short time and to get rid of the more evanescent small-scale features of the precipitation pattern. Indeed, Tatehira *et al.* (1976) found that a significant improvement in predictability in the case of forecasts up to 4 h ahead could be achieved by degrading the resolution even further, from 20 to 40 km. In either event, Tatehira *et al.* found that more accuracy could be achieved by using extrapolation procedures than by advecting precipitation patterns with the wind at some level.

Step 3.3: Objective linear extrapolation of analysed precipitation fields. There are several objective extrapolation procedures that can be used; they may be summarized as follows:

(i) A cross-correlation technique similar to that used by Austin and Bellon (1974) and Bellon and Austin (1978). In this scheme portions of one radar or satellite picture are matched with portions of a subsequent picture. This procedure has the advantage of taking into account the detailed shape of the radar echo or cloud being tracked, and therefore decreases the chance of mismatches. If there are large differential motions from one part of an area to another, then the pattern of precipitation or cloud must be split into several sub-areas in order to produce useful forecasts.

(ii) Tracking of individual radar echo centroids or clouds using a linear least squares extrapolation (Barclay and Wilk 1970, Wilk and Gray 1970). This method has the advantage of coping well with differential motion, but unless echo or cloud clustering techniques are applied (Endlich *et al.* 1971, Wolf *et al.* 1977) there may be difficulty in matching echoes or clouds that change their shape significantly from one picture to the next.

(iii) Tracking of individual echoes or clouds using parameters describing the shape and intensity profile of the entire echo or cloud complex, instead of taking a single intensity threshold as in (i) and (ii) above (see Duda and Blackmer 1972, Blackmer *et al.* 1973). This type of procedure is complex but it does describe the movement of individual clouds or radar echoes.

The overall forecasting scheme specified in this section calls for a high degree of man–computer interaction in order to optimize the forecast. It is therefore unnecessary to strive for the unattainable goal of an objective technique which produces perfect results in all weather conditions.

* The figure of 20 km is somewhat arbitrary; the choice of the most suitable grid size for forecasting will be made in the light of experience.

Step 3.4: Subjective intervention to amend obvious defects in the previous objective extrapolation. The previous step is capable of generating a sequence of forecast patterns over a series of 30-min intervals. This sequence can then be replayed in time-lapse as a continuation of the earlier sequence of analysed precipitation patterns. Shortcomings in the objective extrapolation will show up as discontinuities in the time-lapse sequence which can be ameliorated by subjective modification of the velocity and/or intensity of the precipitation pattern within selected sub-areas.

Step 3.5: Introduction of trends in intensity predicted by a mesoscale numerical dynamical model. The forecasts generated so far are merely linear extrapolations of the most recently observed precipitation pattern. Any broad trends in intensity predicted on the basis of a NWP model can now be introduced provided that they are not inconsistent with the observed trends.

Step 3.6: Subjective reintroduction of major storm cores lost in the earlier filtering process. Thunderstorm cores may have been smoothed out during Step 3.2. Although it is probably appropriate that this should have been done, in view of the lack of persistence of individual convective cells (Wilson 1966), compact clusters of thunderstorm cells sometimes persist much longer than the component cells. If this appears to be happening on a given occasion it may be helpful to reintroduce a few of the major storm centres at appropriate locations perhaps on the basis of a subjective interpretation of the previous time-lapse sequence.

Step 3.7: Reintroduction of orographic effects. At the beginning of the forecast sequence (Step 3.1) we were at pains to rid the precipitation pattern of orographic effects to enable the advective forecasting scheme to function properly. The final step in the forecast procedure is to reintroduce the orographic effects with 5 km resolution. The knowledge of the 'disenhancement' carried out in Step 3.1 should help in applying an appropriate 're-enhancement', assuming that changes in orographic effects occur only slowly, or in a predictable manner as, for example, at the passage of well-defined cold fronts (Browning *et al.* 1975). Having completed this step, one then has a complete set of very-short-range forecasts consisting of a sequence of identically displaced precipitation patterns subjected to varying topographical modification as the precipitation areas pass across different locations over a period of several hours. These forecast patterns are on a 256×256 $(5\ \text{km})^2$ grid and are now ready for dissemination.

(e) *Dissemination of the actual and forecast precipitation information*

The crucial aspects of dissemination are that the information should reach the users quickly, should be frequently updated, and should be in sufficient detail and in an appropriate format. Three dissemination formats are indicated in Figure 6. All the formats shown in Figure 6 involve some form of visual display* for clarity and ease of assimilation or, alternatively, the data can go straight into the user's computer system. All the formats can be disseminated automatically via standard land-lines. Very frequent updating is possible.

One of the obstacles to speedy dissemination is the amount of prior data processing required in Stages 2 and 3. Nevertheless, as a result of the degree of automation and the ease with which the manual interaction can be achieved using interactive video display techniques, these steps are not expected to be as time-consuming as might appear at first sight. It must also be remembered that only a rather small fraction of the display is likely to be filled by precipitation at any given time and, once the data have been processed for a few consecutive times, the processing of subsequent data is made easier by

* Verbal dissemination will of course continue to be used for communicating limited amounts of information.

continuity considerations. We anticipate that the time delay between receipt of the raw data and dissemination of the forecast will be between 15 and 30 minutes. Unfortunately the basic Meteosat data are not received until about 45 minutes after real time. Thus it seems that we should aim to get the forecast product to the users within just over an hour of the time of the latest data used in the derivation of that product. If there is a risk of it taking longer than this, then it will be necessary to bypass or abbreviate some of the less important steps.

Throughout the development of these procedures we shall constantly need to be balancing the benefits of introducing additional steps against the penalties of the extra time and labour involved. In view of the rather long delay in receipt of Meteosat data from source compared with the almost real-time receipt of radar network data, there is, for example, a strong case for also disseminating actual data, based upon an abbreviated analysis of the radars alone, to some users requiring very up-to-date information on current weather.

Conclusions

The plan for very-short-range precipitation forecasting in the United Kingdom, as outlined in this paper contains the following key elements:

- The primary requirement is to *observe the mesoscale field of precipitation* on an almost continuous basis. Sequences of such fields can form the basis of simple *forecasts by extrapolation* in the 1–6 h time frame, and can also be used to help *initialize mesoscale NWP models* for predictions in the 6–24 h time frame.
- It is not an easy matter to observe mesoscale precipitation fields, and data from several sources need to be *carefully analysed and then combined.*
- The most effective tool for the quantitative determination of precipitation fields is *radar*; to get sufficient coverage for forecasting a few hours ahead an *integrated network* of radars is needed.
- To obtain more warning of approaching precipitation systems, especially from data-sparse sea areas in the case of the UK, it is possible to extend the coverage using satellite cloud imagery; only a *geostationary* satellite is capable of providing data frequently enough for very-short-range forecasting. To facilitate the combined analysis of radar and satellite data the two sets of data need to be *reduced to a common format.*
- Vast amounts of data are generated by radar and satellite and this calls for a high degree of automation in the handling of the data; at the same time, however, the imperfections in the observational data and objective forecasting procedures, as well as the ill-defined nature of the transfer function between cloud imagery and surface precipitation intensity, are such that for the foreseeable future *a combination of objective procedures and subjective judgement* will be required in the analysis and forecasting.
- The new technology of *interactive computer-driven video displays* can be exploited to enable the human forecaster to exercise his judgement effectively within the framework of an otherwise highly automated procedure; the degree of interaction required is far greater than that employed in present intervention schemes. All-digital processing is required for flexibility and quantitativeness.
- Detailed forecasts for a few hours ahead are a perishable commodity whose value depends on the ability to distribute them widely and promptly, and in an easily understood format: *new dissemination techniques* such as teletext and viewdata offer this capability.
- Obvious errors and artefacts will be removed during the analysis of the radar data using the interactive video display; this provides the kind of preliminary *quality control* that is necessary if the radar data in addition to being used for real-time forecasting are also to constitute a reliable *mesoscale precipitation archive.*

- The systematic archive of data and the analytical experience gained by regular use of these facilities will provide the means for *improving fundamental understanding* of the structure and mechanisms of mesoscale precipitation systems; this will in turn contribute to further improvement in forecasting techniques.

A pilot forecasting program based on the above plan has been initiated at the Meteorological Office Radar Research Laboratory. Small teams will be working side by side to develop technical facilities, to do basic mesometeorological research and to develop operational forecasting techniques. There will be a combination of real-time operational research and off-line analysis on a case study basis. It is hoped thereby to tailor the technical developments to suit both the operational and research demands and to enable forecasters to take quick advantage of improved understanding. The scheme will be built up in stages and will be operated in a real-time mode over a period of years to establish cost-effectiveness. Although we have focused in this paper on the integration of radar and satellite data, an important extension will be to incorporate other data from the synoptic data bank as a series of overlays to the radar-cum-satellite display.

The man–computer interactive analysis and forecasting will be a centralized activity at first. However, with the decreasing costs being brought about by advances in solid-state technology one can foresee a time when some interactive procedures could be extended to outstations. Such a distributed computer weather-analysis and forecasting network would lead to perhaps the biggest change in meteorological operations since the advent of the large computer: outstation meteorologists would then have a real opportunity to produce significant improvement in their forecast products on the small scales relevant to local needs.

A major change in the mode of operation at regional forecast offices is already under way in the USA with the introduction of the AFOS (Automation of Field Operations and Services) system in which visual display units are replacing hard-copy facsimile charts for the display of synoptic data (Klein 1976). The use of AFOS, along with Model Output Statistics (Glahn and Lowry 1972) and computer-worded forecasts (Glahn 1978; Wickham 1976), will allow forecasts to be produced with fewer outstation staff and less reliance on subjective forecasting skills. However, these same developments have been accompanied by fears that forecasters may give up using their skills altogether, to the detriment of the quality of the operational product (e.g. Snellman 1977). Although the AFOS system provides for interaction in the limited sense of allowing flexible access to different data formats, the FRONTIERS type of concept carries the interaction a stage further and actively encourages the subjective element in very-short-range forecasting. The aim is to seek the right blend of modern technology and the forecasters' skill and understanding. We consider that the FRONTIERS approach will motivate the forecaster to contribute effectively whilst leading to a local forecast product which has a degree of detail and accuracy that has previously been unattainable.

References

Aldcroft, A. E.	1976	System for constant elevation precipitation transmission and recording. (Unpublished report, Atmospheric Environment Service, Toronto, Canada.)
Austin, G. L. and Bellon, A.	1974	The use of digital weather radar records for short-term precipitation forecasting. *Q J R Meteorol Soc*, **100**, 658–664.
Ball, A. P., Browning, K. A., Collier, C. G., Hibbett, E. R., Menmuir, P., Owens, R. G., Ponting, J. F., Whyte, K. W. and Wiley, R. L.	1979a	Thunderstorms developing over North West Europe as seen by Meteosat and replayed in real-time on a fast-replay colour display. *Weather*, **34**, 141–147.

Ball, A. P., Clarke, J. L., Davy, B. D., O'Brien, M. J., Trigg, S. E., Taylor, B. C. and Voller, T. A. 1976 A system for the processing, transmission and remote display of data from a weather radar. (Unpublished report, *Royal Radar Establishment Memorandum* No. 3020.)

Ball, A. P., Clarke, J. L., O'Brien, M. J., Shaw, A. H., Trigg, S. E. and Voller, T. A. 1979b The design and implementation of an operational, computer-based weather radar system. (Unpublished report, *Royal Signals and Radar Establishment Memorandum* No. 3151.)

Balston, D. M. 1978 An image analysis system for earth resource surveys. *Systems Technology* No. 28, Plessey Telecommunications Ltd, Liverpool, 14–24.

Barclay, P. A. and Wilk, K. E. 1970 Severe thunderstorm radar echo motion and related weather events hazardous to aviation operations. *ESSA Tech Memo*, ERLTM-NSSL 46.

Barrett, E. C. 1973 Forecasting daily rainfall from satellite data. *Mon Weath Rev*, **101**, 215–222.

Bell, R. S. 1978 The forecasting of orographically enhanced rainfall accumulations using 10-level model data. *Meteorol Mag*, **107**, 113–124.

Bellon, A. and Austin, G. L. 1978 The evaluation of two years of real-time operation of a short-term precipitation forecasting procedure (SHARP). *J Appl Meteorol*, **17**, 1778–1787.

Blackmer, R. H., Duda, R. O. and Reboh, R. 1973 Application of pattern recognition to digitized weather radar data. Final Report, Contract 1-36072, SRI Project 1287, Stanford Research Institute, Menlo Park, Calif.

Bracken, P. A., Dalton, J. T., Billingsley, J. B. and Quann, J. J. 1977 Atmospheric and oceanographic information processing system (AOIPS): system description. Washington, National Aeronautics and Space Administration, *Tech Memo* X-71342.

Browning, K. A. 1974 Mesoscale structure of rain systems in the British Isles. *J Meteorol Soc Japan*, **52**, 314–327.

1977 The short-period weather forecasting pilot project. (Unpublished report, *Meteorological Office Radar Research Laboratory*, *Research Report* No. 1, copy available in National Meteorological Library, Bracknell.)

1979 Structure, mechanism and prediction of orographically enhanced rain in Britain. (In *GARP Review* 'Orographic effects in planetary flows', editors R. Hide and P. W. White.)

Browning, K. A. and Harrold, T. W. 1970 Air motion and precipitation growth at a cold front. *Q J R Meteorol Soc*, **96**, 369–389.

Browning, K. A., Pardoe, C. W. and Hill, F. F. 1975 The nature of orographic rain at wintertime cold fronts. *Q J R Meteorol Soc*, **101**, 333–352.

Bussell, R. B., Cole, J. A. and Collier, C. G. 1978 The potential benefit from a national network of precipitation radars and short period forecasting. (Paper presented at the Cranfield Conference of River Engineers, July 1978.) London, Ministry of Agriculture, Fisheries and Food.

Carpenter, K. M., Riddaway, R. W. and White, P. W. 1978 The use of very high resolution numerical models for short range forecasting. (Unpublished report, copy available in National Meteorological Library, Bracknell.)

Central Water Planning Unit, Reading 1977 Dee Weather Radar and Real Time Hydrological Forecasting Project. Report by the Steering Committee, Central Water Planning Unit. London, HMSO.

Chatters, G. C. and Suomi, V. E. 1975 The applications of McIDAS. *New York, Inst Electric Electron Eng, Trans Geosci Electron*, GE-13, No. 3, 137–146.

Clarke, J. L. and Collier, C. G. 1977 Assessment of a real-time method for reducing the errors in radar rainfall measurements due to the bright-band. (Unpublished report, *Meteorological Office Radar Research Laboratory, Research Report* No. 3, copy available in National Meteorological Library, Bracknell.)

Duda, R. O. and Blackmer, R. H. 1972 Application of pattern recognition techniques to digitized weather radar data. Final Report covering the period 25 May 1971 to 31 March 1972. Contract 1-36072, SRI Project 1287, Stanford Research Institute, Menlo Park, Calif.

Endlich, R. M., Wolf, D. E., Hall, D. J. and Brain, A. E. 1971 Use of a pattern recognition technique for determining cloud motions from sequences of satellite photographs. *J Appl Meteorol*, **10**, 105–117.

Fujita, T. T., Pearl, E. W. and Shenk, W. E. 1975 Satellite-tracked cumulus velocities. *J Appl Meteorol*, **14**, 407–413.

Glahn, H. R. 1978 Computer worded forecasts. *Preprint Volume, Conference on Weather Forecasting and Analysis and Aviation Meteorology*, 16–19 *October* 1978, *Silver Spring, Md.* American Meteorological Society, Boston, Mass., 374–381.

Glahn, H. R. and Lowry, D. A. 1972 The use of Model Output Statistics (MOS) in objective weather forecasting. *J Appl Meteorol*, **11**, 1203–1211.

Harrold, T. W., English, E. J. and Nicholass, C. A. 1974 The accuracy of radar-derived rainfall measurements in hilly terrain. *Q J R Meteorol Soc*, **100**, 331–350.

Harrold, T. W. and Kitchingman, P. G. 1975 Measurement of surface rainfall using radar when the beam intersects the melting layer. *Preprint Volume, 16th Radar Meteorology Conference, 22–24 April 1975, Houston, Tex.* American Meteorological Society, Boston, Mass., 473–478.

Hill, F. F. and Browning, K. A. 1979 Persistence and orographic modulation of mesoscale precipitation areas in a potentially unstable warm sector. *Q J R Meteorol Soc*, **105**, 57–70.

Hill, F. F., Whyte, K. W. and Browning, K. A. 1977 The contribution of a weather radar network to forecasting frontal precipitation: a case study. *Meteorol Mag*, **106**, 69–89.

Hilyard, J. (editor) 1977 Interactive video displays for atmospheric studies. *Proceedings of a Workshop sponsored by the National Science Foundation at the University of Wisconsin-Madison, 14–16 June 1977.*

Houze, R. A., Hobbs, P. V., Biswas, K. R. and Davis, W. M. 1976 Mesoscale rainbands in extratropical cyclones. *Mon Weath Rev*, **104**, 868–878.

James, P. K. and Browning, K. A. 1979 Mesoscale structure of line convection at surface cold fronts. *Q J R Meteorol Soc*, **105**, 371–382.

Johnson, G. N., Smith, P. L., Nathanson, F. E. and Brooks, L. W. 1975 A study of techniques for reduction of anomalous propagation problems in weather radar data systems. Report 75–2, Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, NOAA-National Weather Service, Contract No. 4-35341.

Klein, W. H. 1976 The AFOS program and future forecast applications. *Mon Weath Rev*, **104**, 1494–1504.

Kreitzberg, C. W. 1969 Prospective applications of models to forecasting. *Bull Am Meteorol Soc*, **50**, 947–955.

1976 Interactive applications of satellite observations and mesoscale numerical models. *Bull Am Meteorol Soc*, **57**, 679–685.

Kreitzberg, C. W. and Rasmussen, R. G. 1977 Data simulation studies for field programs, satellite system tests, and regional weather prediction. *Preprint Volume, 3rd Conference on Numerical Weather Prediction, 26–28 April 1977, Omaha, Nebr.* American Meteorological Society, Boston, Mass., 423–430.

Lovejoy, S. and Austin, G. L. 1979 The delineation of rain areas from visible and IR satellite data for GATE and mid-latitudes. *Atmosphere–Ocean*, **17**, 77–92.

Meteorological Office 1978 Annual Report 1977. London, HMSO, 7 and 12–13.

Parker, J. 1978 Meteorological Office participation in Prestel—the Post Office viewdata system. *Meteorol Mag*, **107**, 249–254.

Purdom, J. F. W. 1976 Some uses of high-resolution GOES imagery in mesoscale forecasting of convection and its behaviour. *Mon Weath Rev*, **104**, 1474–1483.

Reynolds, D. W., Brown, M. L., Smith, E. A. and Vonder Haar, J. H. 1978 Cloud type separation by spectral differencing of image pairs. *Mon Weath Rev*, **106**, 1214–1218.

Saffle, R. E. 1976 D/RADEX products and field operation. *Preprint Volume, 17th Conference on Radar Meteorology, 26–29 October 1976, Seattle, Wash.* American Meteorological Society, Boston, Mass., 555–559.

Scofield, R. A. and Oliver, V. J. 1977 A scheme for estimating convective rainfall from satellite imagery. *NOAA Tech Memo*, NESS 86, Washington, D.C.

Scofield, R. A. and Weiss, C. E. 1977 A report on the Chesapeake Bay Region Nowcasting Experiment. *NOAA Tech Memo*, NESS 94, Washington, D.C.

Smith, E. A. and Reynolds, D. W. 1978 The generation and display of digital radar satellite composites using analytic mapping techniques and solid state video refresh technology. *Preprint Volume, Conference on Weather Forecasting and Analysis and Aviation Meteorology, 16–19 October 1978, Silver Spring, Md.* American Meteorological Society, Boston, Mass, 201–205.

Smith, W. L., Hayden, C. M., Woolf, H. M., Howell, H. B. and Nagle, F. W. 1978 Satellite sounding applications to mesoscale meteorology. (Unpublished manuscript, presented at the Symposium on Remote Sounding of the Atmosphere from Space, COSPAR XXI, Innsbruck, June 1978.)

Snellman, L. W. 1977 Operational forecasting using automated guidance. *Bull Am Meteorol Soc*, **58**, 1036–1044.

Tatehira, R., Sato, H. and Makino, Y. 1976 Short-term forecasting of digitized echo pattern. *J Meteorol Res*, **28**, 61–70 (English abstract on p. 61).

Taylor, B. C. 1975 A mini-network of weather radars. *Preprint Volume, 16th Radar Meteorology Conference, 22–24 April 1975, Houston, Tex.* American Meteorological Society, Boston, Mass., 361–363.

Taylor, B. C. and Browning, K. A. 1974 Towards an automated weather radar network. *Weather*, **29**, 202–216.

Thormeyer, C. D. 1978 Use of the Naval Environmental Display Station (NEDS) in the solution of Navy environmental forecast problems. *Preprint Volume, Conference on Weather Forecasting and Analysis and Aviation Meteorology, 16–19 October 1978, Silver Spring, Md.* American Meteorological Society, Boston, Mass., 211–214.

Try, E. F. 1972 Remoting of CAPPI pictures by computer. *Preprint Volume, 15th Radar Meteorology Conference, 10–12 October 1972, Champaign-Urbana, Ill.* American Meteorological Society, Boston, Mass., 189–197.

Wickham, P. G. 1976 The interpretation and presentation of numerical forecast data, in 'Papers presented at the WMO Symposium on the Interpretation of Broad-scale NWP Products for Local Forecasting Purposes, Warsaw, October 1976'. Geneva, WMO No. 450, 213–221.

Wilheit, T. T., Chang, A. T. C., Rao, M. S. V., Rodgers, E. B. and Theon, J. S. 1977 A satellite technique for quantitatively mapping rainfall rates over the oceans. *J Appl Meteorol*, **16**, 551–560.

Wilk, K. E. and Gray, K. C. 1970 Processing and analysis techniques used with the NSSL weather radar system. *Preprint Volume, Proceedings of 14th Radar Meteorology Conference, 17–20 November 1970, Tucson, Ariz.* American Meteorological Society, Boston, Mass., 369–374.

Wilson, J. W. 1966 Movement and predictability of radar echoes. National Severe Storms Laboratory, *Tech Memo* No. 28, Norman, Okla.

Wolf, D. E., Hall, D. J. and Endlich, R. M. 1977 Experiments in automatic cloud tracking using SMS–GOES data. *J Appl Meteorol*, **16**, 1219–1230.

Woodroffe, A. 1976 The 'man–machine' mix at RMC Bracknell, in 'Papers presented at the WMO Symposium on the Interpretation of Broad-scale NWP Products for Local Forecasting Purposes, Warsaw, October 1976'. Geneva, WMO No. 450, 170–175.

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Noctilucent clouds over western Europe during 1978

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Table I summarizes the observations of noctilucent clouds (NLC) over western Europe during 1978 which have been reported to the Department of Meteorology, University of Edinburgh. The co-operation of the Swedish meteorological authorities is welcomed. The information they provide enlarges the area of coverage previously watched over by voluntary observers in Denmark and Norway.

A grant from the Meteorological Office finances the collection, collation and publication of the written and photographic data.

Observers are asked to report for the period May–August (inclusive), mid-May to mid-August encompassing the main observing 'season' in the northern hemisphere. The immediate effect of the Swedish observations is to show an increase in number and in depth of observations of the clouds during the first two weeks of August. It will be a matter of interest to see if the data from the higher latitude stations make this a regular feature of the collection.

The reader is asked to note that the times given in the second column of the Table are not necessarily the total duration of the NLC display, though appearance and disappearance times are referred to in the notes, where known. Observers from widely different areas reported worse than usual tropospheric cloud obstruction to viewing during 1978, and cloud-free regions were at times too restricted to allow of a sure assessment of longitudinal extent of the cloud field.

In the third column of Table I brief notes of the displays enlarge on the facts listed in the remaining columns, referring to photographs and sketches available. Further information will be provided wherever possible, if requested.

Positive reports of NLC were received from 16 stations of the Meteorological Office network of Great Britain, one station of the Irish Meteorological Service and 11 stations of the Swedish Meteorological & Hydrological Institute and from a special NLC observing aircraft operating over Sweden. Positive reports from voluntary observers included those from the Fair Isle lighthousekeeper, Whitby coastguard and experienced contributors of many years from Newton Stewart, Milngavie, Fort Augustus, Enfield, Rønne and Fiane. Photographs and sketches of great detail and artistry were a welcome addition whenever provided.

Routine hourly observations for hours of darkness were received from 16 meteorological stations and form an important part of the data collection, particularly where conditions are sufficiently clear to allow an observer to state confidently 'No NLC'. These records are supplemented by voluntary observers, in many instances, who are providing lists of negative observing periods. The Swedish data summary lists the prevailing tropospheric conditions with details as to the degree of possibility of ascertaining the presence or absence of the clouds. 'Negative' nights are significant, particularly during a possibly unbroken series of appearances of NLC. They are also a helpful point of reference when NLC is suspected by a single observer in the vicinity.

During 1978 NLC sightings were listed on 50 nights; no details are available for a few of these, and others are recorded as 'suspected' only. There seem to have been few outstanding displays; the brightest, most widely viewed and most extensive occurred during July, that of 10/11 July being seen as 'brilliant' from western Scotland, and observers in Gotland were favoured with some bright displays.

More displays were recorded for July than for June, the fortnightly periods of the former showing 12:11 against 6:8 for June. Eight were recorded in the first fortnight of August. The starting date for positive observations, 25–26 May for 1978, is 11 days and some 5 displays later than in 1977, and compares rather with 1973, 1974, and 1976. There were no displays reported outside the expected end-of-season dates.

In Edinburgh time-lapse photography was carried out throughout the observing season; on occasions there NLC was detected by eye, but conditions for protracted filming were unfavourable. Photographs were received from Fort Augustus (0030 h 18/19 June) and from Rønne (2255 h 18/19 June) and Alrö (2205–2230 27/28 June).

We are grateful for all the information received to enable the compilation of this list and congratulate observers on the quality of their reports.

Table I. *Displays of noctilucent clouds over western Europe during 1978*

Date—night of	Times UT	Notes	Station position*	Time UT	Max. elev.	Limiting azimuths
					degrees	
25/26 May	2300–0100	Low elevation veil to N and band in NNE, fading to veil only in NNE.	56.5°N 03°W	2300	10	350–040
				2400	7	010–030
26/27	0300	Wispy NLC 'plumes' in NNE; veil NE–E.	55.5°N 01.5°W	0300	11	020–090
28/29	0100–0300+	All stations agreeing on high elevation of NLC, with consequent more tenuous appearance; seen finally as strands against blue dawn sky, fading as sun rose.	59°N 03°W	0100	25	350
			57°N 02°W	0100–0200	80	
			55.5°N 04.5°W	0200	24+	300–030
				0300	45	
29/30	2200, 2300 0100, 0200	Suspected NLC, though 'nil' report at 2400 h.	57°N 02°W	2300	9	360
2/3 June	2400, 0100	Faint veil with wisps spreading to higher elevation.	55.5°N 01.5°W	0100	30	340–030
			55°N 04.5°W			
4/5	0100	Broken band of NLC—not visible at 0200 h.	54.5°N 06°W	0100	25	340–030
8/9	0010	Faint NLC visible through broken tropospheric cloud to N.	56°N 03°W		10	330
10/11	2340, 0100	Faint NLC to N.	55.5°N 05.5°W	0100	7	360
			55°N 04.5°W			
12/13	2300–0100	NLC visible through breaks in tropospheric clouds—later complete coverage of low cloud. Indications of extensive azimuth spread of NLC.	57.5°N 03.5°W	0100	25	350–090
			57.5°N 07.5°W	2300	—	350–020
			56°N 03°W	2355	8	360
			55°N 04.5°W			
13/14	2315–0300	Extensive display, carefully sketched at Kinloss and Fort Augustus, with all the various forms visible; brightest 2400–0030 h.	57.5°N 03.5°W	2400	46	330–070
				0100	46	330–070
			57°N 04·5°W	2315	20	360
				2345	60	305
					25	308–360
					35	004
				0030	60	315
					30	350–050
			56·5°N 07°W	0100	12	340–030
				0300	7	045
			55·5°N 03°W	2400	11	020
			55·5°N 04·5°W			
16/17	2350	Probable NLC (conditions of very good visibility, but moonlight).	55·5°N 04·5°W			
18/19	2145–0245	Earliest report from Sweden, latest sighting from Newcastle, most southerly from Bedford. At Fort Augustus display brightest 0030 h when a vivid blue striated band stretched in N–S direction (photograph). Display seen from Leeming (0040 h) as 3 bright bands radiating fanwise, with cross billows developing in centre of the 'fan'. From Bedford 5 or 6 bands visible, angled at 45° NNE towards SW. Photographs taken serially 2330–2400 at Milngavie.	57·5°N 18·5°E	2200	15	350–020
				2350	30	350–020
				0020	25	340–010
			57°N 04·5°W	0015	28	044
				0030	32	360–045
			56°N 04·5°W		40	
			56°N 03°W			
			55·5°N 04·5°W			
			55°N 01·5°W	0145	15	340–040
				0245	20	330–020
			55·5°N 01·5°W			
			55°N 04·5°W	0040	15	360
			54·5°N 01·5°W	0040	12	330–045
			52°N 0·5°W	0200	45	340–020

* to nearest 0·5 degree.

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths
					degrees	
19/20	2200–0200	No details.	56°N 03°W			
			55·5°N 01·5°W			
20/21	0245	At 0200 h 'No NLC' in almost clear skies. At 0245 h very faint patch of NLC visible—faded 0308 into sunrise.	59°N 03°W	0245	18	030
23/24	2200	No details of early sighting. Extensive formation of billows and band visible to high elevation from Visby.	59·5°N 18°E			
	2340–0040		57·5°N 18·5°E	2340	45	360–090
				0015	30	340–360
					50	030–100
24/25	2230–0100	Banded veil formation to high elevation remaining constant, brightest 2300 h.	57·5°N 18·5°E	2230	50	330–030
				2300	60	340–030
26/27	2330	NLC visible through breaks in tropospheric cloud—photographs.	56°N 03°W			
28/29	2255–2345+	Faintly at first, but with increasing brightness, NLC (thin bands and billows) reached max. elevation at 2325 h. New formations appeared NNE horizon and moved in westerly direction.	55°N 14·5°E	2315	15	315–020
				2325	25	
30 June/1 July	2350	Probable NLC to N.	56°N 03°W			
1/2 July	2230	Faint patch of NLC with single bright band, above tropospheric clouds to 8°.	55°N 14·5°E	2230	12	360
2/3	2250	Presence of NLC strongly suspected visible through breaks in tropospheric cloud.	56°N 03°W			
4/5	2330, 0100	Low elevation, short-lived appearance of NLC seen central and SW Scotland, partially obscured to N by tropospheric clouds.	56·5°N 03°W	0100	5	340–020
			55·5°N 05·5°W			
			55°N 04·5°W			
5/6 July	2300, 0300	NLC visible in gaps in 7/8 tropospheric cloud cover.	57·5°N 07·5°W			
			56°N 03°W			
6/7	2315–0045	Sufficiently clear conditions before 2300 h to decide NLC not visible. After 2315 h medium brightness formation of veil, bands, billows and whirls to high elevation; varying brightness (very bright at Visby 0015 h). After 0045 h increasing tropospheric cloud.	58°N 14°E	2330	90	300–070
				2400	80	300–070
				0200	80	300–050
			57·5°N 18·5°E	2315	25	350
				0015	35	330–020
7/8	2155–2330	Medium brightness NLC showing whirl formation at high elevation.	59·5°N 18°E			
			58°N 14°E	2300	80	320–060
8/9	2045–0100	A bright display of NLC as viewed Gotland with all forms visible, increasing to cover most of N sky. Faded quickly after 0045; no longer visible at 0115 h though viewing conditions still good. Seen through breaks in tropospheric clouds from Northumbria, and suspected at Edinburgh. (Photographs—Paviken)	57·5°N 18·5°E	2045	30	350–030
				2145	40	340–030
				2300	90	300–090
				0015	75	280–070
				0045	30	280–350
			56°N 03°W			
			55·5°N 01·5°W	0100	10½	
9/10	2300, 2320	Possibly small patch of NLC at high elevation.	57·5°N 03·5°W	2300	80	360
			55°N 04·5°W			
10/11	2115–0215	Widely observed display, brilliant as seen W Scotland. At Jönköping NLC spread to 45° max. elevation; seen as bands to elevation 3° from N Yorkshire.	58°N 14°E	2230	30	340–030
				2345	45	330–020
				0015	45	340–020
			57·5°N 07·5°W	2400	12	340–020
			56·5°N 07°W	0100	4	330–030
				0200	9	040
			55·5°N 10°E	2115	30	315–045
				2130	35	290–045
			55·5°N 05·5°W	2400	15	315
			55·5°N 01·5°W	2300	12	300–020
				0100	11	360–030
				0145	13	360–010
			54·5°N 01·5°W	2330	3	310–320
				2400	2	340–040
			54·5°N 00·5°W			
12/13	2153–2400	No details.	59·5°N 18°E			
13/14	2030–0045	First noted as bright amorphous spread of NLC: bands and billows developed and were discernible to end of display. At 0045 h no NLC visible in clear observing conditions.	59·5°N 18°E			
			57·5°N 18·5°E	2115	30	300–030
				2215	60	310–020
				2315	30	330–030
				0015	45	320–070
			55°N 04·5°W	2350		

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
14/15	2200–2400	No details.	59·5°N 18°E			
			55°N 04·5°W			
17/18	2125–0245	Earliest sighting Alrø (Denmark) when banded structure to 4° elevation discerned through binoculars. Noted soon after at Visby (Gotland) when bright bands and whirls visible to 40° elevation. No further NLC visible there at 2345 h, though viewing conditions good. At 2220 h bright bands and whirls to 70° elevation seen at Jönköping. There, too, an hour later no NLC visible in clear conditions. In E Scotland NLC suspected 0050 h and at 0140 h clearing of tropospheric clouds to E revealed very bright bands to 37° elevation. At 0225 h azimuthal spread to 130°, with many forms parallel to horizon and more tenuous filaments in N–S direction. NLC mainly obscured by tropospheric cloud at 0245 h though billows still visible in cloud breaks to 20° elevation ENE (sketches). Bands and billows seen briefly but bright in NE England to approx. 10° elevation at 0150 h. No details of farthest N sighting at Arlanda/Bromma.	59·5°N 18°E			
			58°N 14°E	2220	70	350–360
			57·5°N 18·5°E	2145	40	340–020
				2315	30	
			56·5°N 03°W	0140	37	020
				0215	40	340–060
				0225	22	?–130
				0235	35	040
			56°N 10°E	2125	4	045
				2200	10	045
			55·5°N 01·5°W	0150	8	355–005
			54·5°N 01·5°W	0145	10	340–020
18/19	2140–2345 0150–0215	NLC visible through breaks in tropospheric clouds from Edinburgh and Bedford. Seen as veil with brighter patches; whirl formation suspected by more southerly observer.	56°N 03°W		15	320–040
			52°N 00·5°W	0200	5	355–030
19/20	2400	Probable NLC seen from Edinburgh.	56°N 03°W			
20/21	2215–0020	No details.	59·5°N 18°E			
22/23	2100–0100	NLC to high elevation over mid and southern Scandinavia—bands, billows and whirl formation: brightness no more than moderate.	64°N 10·5°E	2130	30	340–020
				2230	40	320–020
				2330	50	310–020
			61°N 14°E	2215	90	360
			59°N 09°E	2205	60	345–070
			57·5°N 18·5°E	2200	15	330–020
			57·5°N 12·5°E	0100	30	340–010
			56°N 12·5°E	2215	6	350–010
23/24	2225–2400 0140–0300	Earlier sighting from Sundsvall limited by tropospheric clouds though viewing conditions still 'possible' when NLC no longer visible at 2205 h. Later sightings from Dyce and Kinloss both sketched to show compacted area of bands with firm E edge. At latest sighting, from Rosslare, banded veil spread to high elevation N–ENE.	62·5°N 17·5°E	2225	30	330–040
			61°N 14°E			360
			57·5°N 03·5°W	0200	15	040–050
				0220	18	360
			57°N 02°W	0140	18	340–040
				0235	25	325–360
			56°N 03°W			
			52·5°N 06·5°W	0200	6	360–060
				0300	30	360–070
24/25	2250	Probable NLC to N.	56°N 03°W			
26/27	2300 2340–0230	Scottish stations reported striated veil with multiple 'bolder' bands. From more northerly station wisps of NLC also seen to higher elevation.	59·5°N 18°E			
			57·5°N 03·5°W	2400	35	360–030
				0100	35	360–030
			57°N 02°W	2400	15	005–012
			56°N 03°W			
27/28	2140–2300 0200–0230	NLC seen at Alrø through breaks in tropospheric cloud: photographed there 2205–2230 h during peak brightness. From Scotland east part of display obscured. Sketched visible area shows fine ripples, multiple parallel bands and denser patches of NLC. Positive report from Swedish NLC observing aircraft 2140–2230.	63°N 17–20°E			
			57·5°N 03·5°W	0200	20	340–010
			56°N 10°E	2155	13	290–345
			56°N 03°W			
28/29	2300–0230	Display at peak brightness and extent 0100–0200 h; viewed mainly between tropospheric clouds but in clear conditions from Dyce: sketches show multiple bands and whirls against veil background; weak veil noted to 50° elevation at 0145 h. Faded into brightening sky around 0215 h.	61°N 14°E	2400		290–360
			60°N 01°W			
			59·5°N 01·5°W			
			59°N 03°W			
			57·5°N 03·5°W	0200	12	360–020
			57°N 02°W	0030	25	330–015
				0130	30+	315–030
				0145	50	
			55·5°N 01·5°W	2400	2	340–010
				0100	4	350–010
				0200	8	340–030
30/31	2130–2200	No details.	63°N 17–20°E	2130		
			61°N 14°E	2145		315–360

Date— night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
2/3 Aug.	2220–2400+	Medium brightness herring-bone formation to high elevation. Fog obscured observations at 0020 h.	62·5°N 17·5°E	2220	30	010–040
6/7	2200–0100	Billows against veil background—medium brightness, decreasing towards end of sighting.	63°N 17–20°E 62·5°N 17·5°E	2330 0030	20 15	360–030 360–030
8/9	2150–2350	Display visible N Sweden—SE Norway—mainly seen as extensive veil, though billow formation noted Umeå. No NLC visible by midnight GMT in clear sky conditions.	65·5°N 22°E 64°N 20·5°E 62·5°N 17·5°E 59°N 09°E	2200 2230 2320 2330 2215	 20 15 15 90	345 310–360 300–330 330–030 345–090
9/10	2235–2345	Faint NLC noted for short periods from NLC observing aircraft and later from Sundsvall—billow formation seen NNE.	63°N 17–20°E 62·5°N 17·5°E	0200	10	020–030
10/11	2150–2205 2230–0130	Short-lived veil and band of NLC; medium brightness seen at Sundsvall in clear sky conditions. No details of more southerly sighting.	62·5°N 17·5°E 55·5°N 13·5°E	2200	80	360–040
12/13	2215–0100	Faint NLC seen from NLC observing aircraft.	63°N 17–20°E			
13/14	2240–0014 0100–0200	Veil of NLC, extensive but faint. Earlier sighting from aircraft.	63°N 17–20°E 62·5°N 17·5°E	0100 0200	30 30	300–010 300–010
14/15	2330–0230	Faint NLC veil observed constantly over 3 hours.	62·5°N 17·5°E 61°N 14°E 59·5°N 18°E	2340– 0230	15	340–060

Reviews

Microphysics of cloud and precipitation, by H. R. Pruppacher and J. D. Klett. 180 mm × 245 mm, pp. xiv + 714, *illus.* D. Reidel Publishing Co., Dordrecht, Holland, 1978. Price Dfl 85.00.

The title of this scholarly and useful book is rather misleading in that it contains much that is only marginally relevant to clouds and precipitation and does not attempt to get to the heart of cloud physics which is concerned with the evolution of populations of hydrometeors within a framework of cloud dynamics.

Some idea of the content and balance of the book may be given by noting that after a chapter of only 35 pages describing the microstructure of clouds and precipitation, nearly 100 pages are devoted to the thermodynamics of aqueous phase changes and to the structure and surface properties of the water substance. Fifty pages are allocated to the mechanics of aerosols, much in the spirit of Fuchs's classical text, and 45 pages to the effects of electrical forces on the evolution of clouds and precipitation which, in the reviewer's judgement, could have been omitted as being of very little importance. Two of the most valuable and relevant chapters for cloud physicists are those given to the collision and coalescence of cloud particles but one might question whether the present state of knowledge of these topics merits 80 pages of text.

The treatment of all topics is detailed and thorough with more emphasis on formal mathematical presentation than on experiment and physical insight. The reader's patience is often tested by having to follow the authors through a long mathematical argument which leads to no useful physical result until they make a crucial, simplifying assumption or an appeal to experiment which they could have done much earlier. The text is well and clearly written but is not helped by the heavy, mathematical symbolism and type, the small diagrams relieved by very few photographs and hardly a single diagram of experimental apparatus. Even Dr Pruppacher's own beautiful experiments on the aerodynamics and growth of single hydrometeors receive much less than their due.

However, it is perhaps not quite fair to criticize the authors for not writing a different kind of book. They have obviously tried to produce a text quite different from the standard works on cloud physics but their restricted view of the subject hardly merits a book of this length. In following all the mathematical detail (not to mention the 18 mathematical appendices) the student will find it difficult to see the wood for the trees, for there is little attempt to set the individual topics in their wider context and link them in a manner that gives a feeling for the subject as a whole. This book contains much that is admirable and useful but there is no whiff of the atmosphere, no glimpse of real clouds, and few hints of the most important of the unsolved problems in cloud physics. For me, it fails to convey the fun and the excitement of the subject; it impresses but does not inspire.

B. J. Mason

Scientific aspects of the 1975–76 drought in England and Wales (A Royal Society discussion organized by Sir Charles Pereira, F.R.S., O. Gibbs, H. L. Penman, F.R.S. and R. A. S. Ratcliffe on behalf of the British National Committee on Hydrological Sciences, held on 28 October 1977). The Royal Society of London. 240 mm × 170 mm, pp. vii + 133, *illus.* The Royal Society, 6 Carlton House Terrace, London SW1Y 5AG, 1978. Price £6.50 (United Kingdom addresses, including packing and postage) and £6.70 (overseas addresses, including packing and postage).

The 1975–76 drought was discussed at the Royal Society in London on 28 October 1977. This book is the official account of the meeting; all papers except the first deal with hydrological aspects of the drought and its effects on the water supply industry and on agriculture in England and Wales.

The paper by Ratcliffe on 'Meteorological aspects of the 1975–76 drought' covers and extends material contained in papers published in the *Meteorological Magazine* dated May 1977. The description of features of the broad-scale atmospheric circulation, the anomalous rainfall distribution, the unusually cold sea surface over the Pacific etc., is excellent. Several interesting synchronous interrelationships between atmospheric circulation, sea temperature anomalies and large-scale weather are presented with clarity. The 'explanations' of the drought in terms of feed-back between ocean and atmosphere and persistence effect of the dry soil produced by the drought are suggestive and plausible although not objectively convincing. There is a surprising statement on p. 9 that 'All the statistical evidence . . . suggested a breakdown to a normal unsettled summer pattern' (in 1976). In fact, the pressure anomaly rules for predicting seasonal rainfall over England and Wales, published by the reviewer in the *Meteorological Magazine*, correctly indicated not only the dry summer of 1976 but also the dry winter 1975–76, the dry spring 1976 and the wet autumn 1976 (see *Weather* **32**, 1977, p. 325).

Carter gives a straightforward account of 'The effect of the drought on British agriculture'. Lack of water and weather-related diseases and pests seriously restricted crop yields and affected quality, but livestock survived the drought fairly well. The long-term effects on agriculture seem to have been small.

The rest of the book is concerned with hydrological aspects. Clarke and Newson analyse hydrological observations at several experimental catchments. The marked variations in the severity of the drought on stream flow are largely explained by differences in catchment characteristics, in underground water storage and in land-use. The authors stress the importance to water management of future changes in land-use from pasture to forest in upland areas where many major reservoirs are sited.

Day and Rodda deal with 'The effects of the 1975–76 drought on groundwater and aquifers' by discussing well hydrographs covering four years to 1977 for several places and by comparing the observations with long-period data. Well levels had fallen below previous records in many places by late summer 1976, but no adverse long-term effects on aquifers seem to have occurred.

A long paper by Hamlin and Wright gives much information on the low flows in many river systems. River-flows are related to catchment rainfall and soil moisture deficit and the low flows in 1975–76 are put in historical perspective. The severity of the 1975–76 drought in different river systems was extremely variable: for durations of a month or two in some rivers (for instance the Severn) the return period exceeded 200 years but for durations of many months in most rivers it was much less.

As pointed out by Davies, the chemical and biological effects on the quality of surface- and groundwater arising from the drought are evidently complex and varied.

Apart from a short summing-up by Pereira, the last paper is by Gibb and Richards and deals with 'Planning for development of ground water and surface water resources'. After assessing the water resources of England and Wales, they describe the build-up to serious water shortages in the summer of 1976. The authors outline long-term plans for developing water resources, based to some extent on the experience of the drought.

This book puts on record many facts and shows that progress has been made in scientific understanding, especially regarding hydrological aspects of drought. Many thought-provoking ideas are presented, but the root-causes of the abnormal atmospheric behaviour which resulted in the drought and ultimately in its breakdown are still unknown.

R. Murray

References

Miles, M. K.	1977	Atmospheric circulation during the severe drought of 1975–76. *Meteorol Mag*, **106**, 154–164.
Murray, R.	1972a	An objective method of foreshadowing winter rainfall and temperature for England and Wales. *Meteorol Mag*, **101**, 97–110.
	1972b	Prediction of summer rainfall and temperature for England and Wales from anomalous atmospheric circulation in spring. *Meteorol Mag*, **101**, 253–264.
	1973	Forecasting seasonal rainfall and temperature for England and Wales in spring and autumn from anomalous atmospheric circulation over the northern hemisphere. *Meteorol Mag*, **102**, 15–26.
	1977	The 1975–76 drought over the United Kingdom—hydrometeorological aspects. *Meteorol Mag*, **106**, 129–145.
Ratcliffe, R. A. S.	1977	A synoptic climatologist's viewpoint of the 1975–76 drought. *Meteorol Mag*, **106**, 145–154.

Letter to the Editor

Forecasting for the escape of Scharnhorst and Gneisenau

I read the article which appeared in the *Meteorological Magazine*, 107, 1978, pp. 321–338, 'Forecasting for the escape of Scharnhorst and Gneisenau' with great interest and found it fascinating reading. I believe, however, that there may have been some errors in the translation. The Editor assumes (page 323) that Island (Iceland) must be a typing error and translates it as Ireland. The text states that there were four regular daily flights, two of which covered Ireland and the Irish Sea. The 'important gap' referred to must surely be Iceland and the 500 km wide zone between Iceland and Scotland.

Secondly the Editor expresses doubt over the translation of the following passage (page 329): Die Basis würde in gleichem Maβe schlechter, als der Kampfraum wieder aufklart. I believe that die Basis should be translated as the Base and not the Bases (German, die Basen) which makes the sentence read:

'The weather over the base (Brest) would be deteriorating as it again improved over the battle area (Dover Strait). In the afternoon the base would again have favourable weather'.

R. F. Lovett,
Lieutenant Commander,
Royal Navy.

RN School of Meteorology and Oceanography,
RNAS Culdrose

[The translation of Dr Stöbe's text was carried out by several people in consultation, using the first English version as a basis. The original German of the first passage to which Commander Lovett refers is as follows:

Da die Flüge nur einmal am Tage stattfanden, jeweilig also 24 Stunden zwischen den einzelnen Beobachtungen lagen, bildeten sie doch nur einen notdürftigen Ersatz für die sonst üblichen laufenden Wettermeldungen normaler Zeiten. Die sehr fühlbare Lücke Island und ein durch die Flüge nicht erfaßter Raum zwischen Irland und Schottland von fast 500 km Breite blieben immer bestehen. Ganz vereinzelte Meldungen von England und Irland, teils aufgefangene Wettermeldungen von Flugplätzen, teils Agentmeldungen, waren wohl wichtig, aber durchaus unzureichend.

As regards Iceland versus Ireland, the bother is that Iceland is nearly 800 km from Scotland, not 500; however, the stretch St George's Channel–Irish Sea–North Channel *is* about 500 km long. Hence our perplexity. Editor.]

Notes and news

Appointment of the Director-General as Pro-Chancellor of the University of Surrey

At the annual meeting of the Court of the University of Surrey held on Friday, 19 January 1979, it was agreed unanimously to approve the appointment of Dr B. J. Mason, CB, FRS, Director-General of the Meteorological Office, as Pro-Chancellor from 9 September 1979. He will succeed Sir George Edwards, OM, CBE, FRS, who will retire from office on that date.

Dr Mason has been associated with the University for ten years. He is currently Vice-Chairman of Council, having been a member since 1969, and Chairman from 1971 to 1975.

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NOTICES

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